DUSTY PLASMAS ON THE LUNAR SURFACE M. Horányi, E. Grün, T. Munsat, S. Robertson, Z. Sternovsky, X. Wang (Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392, USA, e-mail: horanyi@colorado.edu)

Introduction: The electrostatic levitation and transport of lunar dust remains an interesting and controversial science issue from the Apollo era. This issue is also of great engineering importance in designing human habitats and protecting optical and mechanical devices. As a function of time and location, the lunar surface is exposed to solar wind plasma, UV radiation, and/or the plasma environment of our magnetosphere. Dust grains on the lunar surface collect an electrostatic charge and contribute to the large-scale surface charge density distribution. They emit and absorb plasma particles and solar UV photons, and provide an electromagnetic interface to the lunar interior. There are several in situ and remote sensing observations that indicate that dusty plasma processes are responsible for the mobilization and transport of lunar soil. These processes are relevant to: (a) understand the lunar surface environment; (b) develop dust mitigation strategies; (c) understand the basic physical processes involved in the repeated build-up and collapse of dust loaded plasma sheaths.

Existing Observations and Outstanding Issues: There is a large number of open questions related to lunar dust transport and its observations. These include: (a) imaging by the TV cameras of Surveyor 5, 6 and 7; (b) the fields and particles measurements by the Suprathermal Ion Detector Experiment (SIDE) of Apollo 12, 14 & 15, and the Charged Particle Lunar Environment Experiment (CPLEE) of Apollo 14; and (c) the dust measurements by the Lunar Ejecta and Meteorite Experiment (LEAM) of Apollo 17 (for a recent review see Colwell *et al.,* Rev. Geophys., 2007).

Figure 1: An unprocessed image of the lunar horizon glow from Surveyor 7 (NSSDC).

Images taken by the television cameras on Surveyors 5, 6, and 7 gave the first indication of dust transport on the airless surface of the Moon. These TV cameras consisted of a vidicon tube, 25 and 100 mm focal length lenses, shutters, and color filters surmounted by a mirror that could be adjusted by stepping motors to move in both azimuth and elevations. Images taken of the western horizon shortly after sunset, showed a distinct glow just above the lunar horizon dubbed horizon glow (HG). This light was interpreted to be forward-scattered sunlight from a cloud of dust particles < 1 m above the surface near the terminator. The HG had a horizontal extent of about 3 degrees on each side of the direction to the Sun (Figure 1).

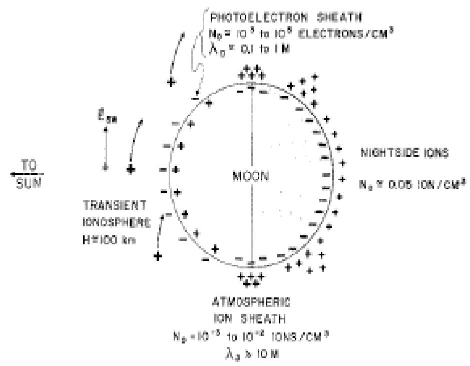

Figure 2: The predicted electrostatic charge density distribution.

An early model of the lunar day side plasma environment indicated that at local noon the photoelectron flux is ≃ 10^{11} $cm^{-2}sec^{-1}$ with an average energy of ≃ 2 eV, giving an electron density of ≃ 4,500 cm^{-3} and a surface potential of +3.5 V. However, measurements of photoelectron yield from lunar soil samples found a lower level of emission, $3x10^9$ $cm^{-2}sec^{-1}$ or 4.5 $\mu A/m^2$. This emission level gives an electron density of only 130 cm^{-3} and a Debye length of ~ 1 m. The typical flow speed is ≃ 400 km/s, and the characteristic temperature of the solar wind plasma is kT ≃ 10 eV. The thermal speed of the solar wind protons is on the order of 40 km/s, much below the flow speed; hence they represent a supersonic flow. On the contrary, the electron thermal speed is close 2000 km/s, much faster than the bulk speed, hence they remain subsonic, and - to a good approximation - the bulk speed can be neglected. Consequently, a void in the solar wind protons behind the Moon could form. However, as electrons separate from the protons, a polarization electric field builds up, accelerating the ions and slowing the electrons, resulting in a filling of the plasma void behind the Moon (Figure 2).

The lunar wake is often modeled as a plasma expansion into vacuum. This expansion leads to enhanced electron temperatures and energetic streaming ion beams towards the surface. Measurements of electrons on the lunar night-side by the Lunar Prospector spacecraft support this simple model and suggest a large negative (< 100 V) night-side lunar surface potential.

The LEAM experiment consisted of 3 sensors.
The EAST sensor was pointed 25 degrees North of East, so that once per lunation its field of view swept into the direction of the interstellar dust flow. The WEST sensor was pointing in the opposite direction as a control for the EAST sensor, while the UP sensor was parallel to the lunar surface and viewing particles coming from above.

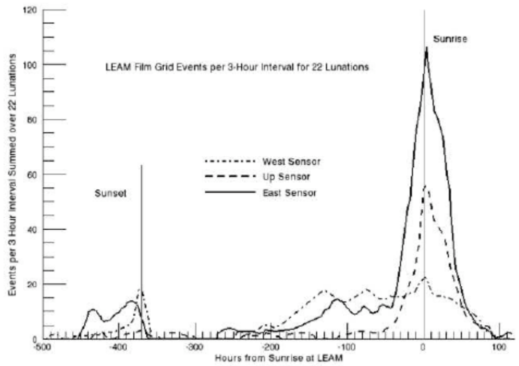

Figure 3. The number of dust impacts per 3-hour intervals integrated over 22 lunation.

LEAM most likely registered slow moving, highly charged lunar dust particles. There were two subsequent studies done to verify this point: a theoretical work to model the response of the electronics, and an experimental study of the LEAM flight spare. The results of the sensor modeling and circuit analysis showed that charged particles moving at velocities < 1 km/s do produce large signals via induced voltages on the entry grids. The experimental study had a similar conclusion: extremely slow moving particles (v < 100 m/s) generate a LEAM signal if the particles carry a positive charge $Q > 10^{-12}$ C. Both of these studies suggest that the LEAM events are consistent with the sunrise/sunset-triggered levitation and transport of slow moving, highly charged lunar dust particles (Figure 3). Assuming a daytime surface potential of+5 V, the **LEAM measurements indicate grains sizes on the order of millimeter in radius, challenging all our current thinking about lunar dust transport.**

This talk will review these existing observations, identify the open issues, and discuss the need for new in situ observations on the lunar surface, and in orbit around the Moon, including imaging, fields and particles, as well as dust measurements. We will compile a preliminary list of science objectives, and discuss candidate instrumentation.

Open questions*:*
Imaging:
1) What is the spatial configuration (location, horizontal and vertical extent) of the horizon glow clouds? Is there a gap between the lunar surface and these clouds that could indicate stably levitated grains?
2) What is the size distribution of the levitated/transported grains in these clouds? Is there a size sorting with height above the lunar surface?
3) How does the cloud change during day/night transitions, and along the lunar orbit?

Fields & particles:
1) What is the charge density distribution on the surface as a function of local time and how does it change along the orbit as the Moon enters the various regions of our magnetosphere?
2) What is the plasma density distribution above the surface, and how does it change with height and time?
3) What is the configuration of the local small-scale electric fields? How do the vertical and horizontal components evolve during the passage of the lit - dark boundary, and along the lunar orbit?

Dust measurements:
1) What is the size, charge, and the velocity of the mobilized lunar dust grains?
2) What is the temporal and spatial variability of the properties of the lofted/transported grains? Is their transport triggered by lit/dark transition or, alternatively, there is an ongoing dust transport that LEAM could only notice at these times?
3) Can interplanetary and interstellar grains be identified and characterized (mass, speed, charge, composition) on the lunar surface?

In addition to lunar science and engineering, these science objectives are of great interest to other disciplines including:
Basic Plasma Science: Understand the buildup and the collapse of plasma and photoelectric sheath, and its changing properties with dust loading. Understand the charging processes of a surface, and of the individual grains resting on it, as a function of the variable properties of the near-surface electric fields and plasma environment.
Planetary and Astrophysical Sciences: Understand the mechanism leading to dust transport on airless bodies. Reliably distinguish between interplanetary and interstellar grains, measure their fluxes, size and velocity distributions, and composition.